fore be stated that, notwithstanding the many difficulties in the way of such studies among primitive peoples, there have been made some serious beginnings in this very important line of anthropological investigation. As to detailed results, nothing can be said until a careful and necessarily tedious elaboration of the data is completed.

The third main object of anthropological field work under the auspices of the Smithsonian Institution during the last three years was the search in Asia for *probable traces of the ancient stock or stocks of mankind, from which the American Indians were derived.* On this subject a number of preliminary reports have already been published[4] and it is unnecessary to do more in this place than to state that such traces undoubtedly exist in Asia to this day, that they extend over a very large territory, and that they are soon to receive further attention by the Smithsonian Institution.

[1] See bibliography in A. A. Ivanovskiji, Ob Antropologičeskom Sostavě Naselenii Rossii, Moskva, 1904.

[2] See Hrdlička's The Painting of Human Bones, etc. *Smithsonian Inst. Rep.* for 1904.

[3] Published in *Smithsonian Inst., Bull. Bur. Amer. Eth.*, No. 34.

[4] Symposium on The Problems of the Unity or Plurality and the Probable Place of Origin of the American Aborigines, *Amer. Anthrop.*, **14,** No. 1, Jan.–March, 1912; Restes, dans l'Asie orientale, de la race qui a peuplé l'Amérique, *Congrès International d'Anthropologie et d'Archéologie préhistoriques, Compte Rendu de la XIV Session*, Genève, 1912; Remains in Eastern Asia of the Race that Peopled America, *Smithsonian Inst., Misc. Coll.*, **60,** No. 16; The Derivation and Probable Place of Origin of the North American Indian, *Proc. XVIII International Congress of Americanists,* and the Genesis of the American Aborigines, *Proc. II Pan-American Sci. Congress*, Washington, 1916.

A THEORY OF NERVE-CONDUCTION

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This research is a continuation of the studies reported in these PROCEEDINGS, **1,** 270, May 1915, and it will therefore be unnecessary to redescribe methods of experimentation. These later experiments were made at the Marine Laboratory of the Carnegie Institution of Washington at Tortugas, Florida, in July, 1915, and the kymograph records were studied in detail in a room which the writer was privileged to occupy in Guyot Hall, Princeton University.

In the experiments of 1914 the distilled water contained between 10^{-5} and 10^{-6} H ion concentration due to carbon dioxide, thus giving an excess of free H ion. The endeavor was therefore made in July, 1915, to obtain neutral distilled water in which both the H and the OH ion concentration approached 10^{-7}. Accordingly, following the suggestion of

Prof. G. A. Hulett, the distilled water was freed in so far as possible from CO_2 by bubbling through it for 60 hours air which had passed through glass tubes containing granulated soda-lime. As the water still appeared slightly acid to phenolpthalein it was rendered alkaline by adding NaOH until the concentration of the OH ion was about $0.75\ n. \times 10^{-5}$.

Although this water was kept in a glass carboy carefully protected from contact with air containing, CO_2 it nevertheless became slowly less and less alkaline, probably due to decomposition of traces of organic matter, so that in the course of 11 days the distilled water became nearly neutral, both the H and OH ion concentration approaching 10^{-7}.

The use of this nearly neutral distilled water in diluting the sea-water should enable one to determine the true effects of the sodium, calcium, and potassium cations of the sea-water without serious disturbances due to H or to OH ions, both of which in weak concentration accelerate and in strong concentration depress the rate of nerve conduction.

Thus we find that a concentration of about 6×10^{-5} OH in sea-water is a maximal stimulant for nerve conduction, but becomes a depressant if its concentration be still further increased.

Experiments were made upon 71 *Cassiopea xamachana* medusæ between July 5 and 16, 1915; the OH ion concentration in the distilled water declining during the course of the experiments from about 10^{-5} to about 10^{-7}. Thus for the first 25 medusæ, when the OH ion concentration was at the start about 10^{-5} and was approaching 10^{-6}, the curve for the decline in rate is fairly well represented by the formula

$$y = 103.37 - 0.541\ (95.2 - x)^{1.18},$$

wherein y is the rate of nerve conduction, the rate in undiluted sea-water being 100 and x the concentration of the sodium, potassium, and calcium cations, their concentration in natural undiluted sea-water being 100.

Later as the OH ion concentration continued to decline the formula became

$$y = 100 - 0.2\ (100 - x)^{1.35},$$

and finally for the last 14 medusæ when the distilled water was still alkaline but nearly neutral, the rate is given by the formula

$$y = 2.512x^{0.8}.$$

This is also equally well represented by the formula

$$y = 100 - 0.778\ (100 - x)^{1.019}.$$

Thus the curves representing the rate of nerve-conduction in sea-water diluted with alkaline distilled water gradually approach and finally become identical with Freundlich's formula for absorption $y = ax^{1/n}$ when the distilled water becomes nearly neutral. In this case $a = 2.512$ and $1/n = 0.8$. The data are shown in detail in Table 1 and Figure 2 at the end of this paper.

Mecklenburg, in *Tables Annuelles Internationelles de Constants et données numérique*, **3**, 418 (1914), gives a list of 16 cases of adsorption in which a ranges from 0.0824 to 23.5 being usually between 2 and 3, while the exponent $1/n$ ranges from 0.167 to 0.965 being usually from 0.2 to 0.6. Hence 0.8 is high, but not beyond the range of the exponent in observed cases of adsorption.

Thus we venture to suggest that adsorption may play a fundamental rôle in nerve conduction, and that the only cations which are necessary to the reaction are the adsorbed sodium, calcium, and potassium ions, the rate of nerve conduction being proportional to the concentration of these adsorbed ions.

Hydroxyl and hydrogen ions are not adsorbed but act independently serving as accelerators of nerve conduction when in weak concentration and as depressants if concentrated to a greater degree.

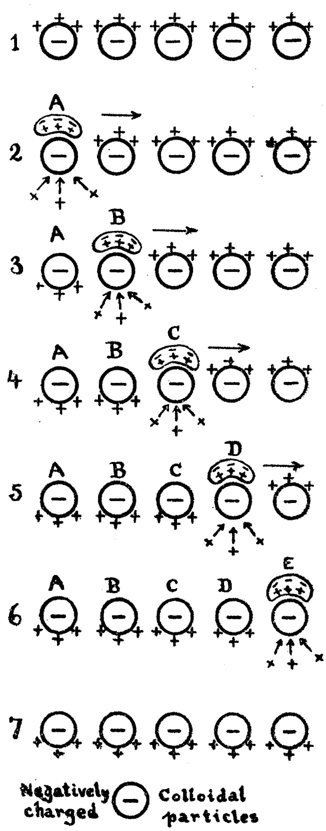

FIG. 1

A series of diagrams may serve to illustrate this hypothesis. Thus in Figure 1 the nerve is represented by a row of negative charged colloidal particles, for the colloid being normally alkaline the charge may be assumed to be negative.[1] Line No. 1 shows the nerve in its resting stage wherein the negative charge of each colloidal particle tends to be partially neutralized by the adsorbed cations of sodium, calcium, and potassium shown by + + +. The number of cations which each colloidal particle can capture and temporarily de-ionize[2] depends upon the potential of its negative charge, and also upon the concentration of the cations in the surrounding fluid. For the sake of illustration we have shown three such cations attracted to the surface of each particle, but in reality the number must be greater than this.

Line No. 2 shows the beginning of a nerve impulse wherein the adsorbed cations of particle A have combined with some anions to form an ion-proteid, thus neutralizing their positive charges and unmasking the negative charge of the colloidal particle. As a result other cations from the surrounding fluid (sea-water) are at once attracted and captured by the particle.

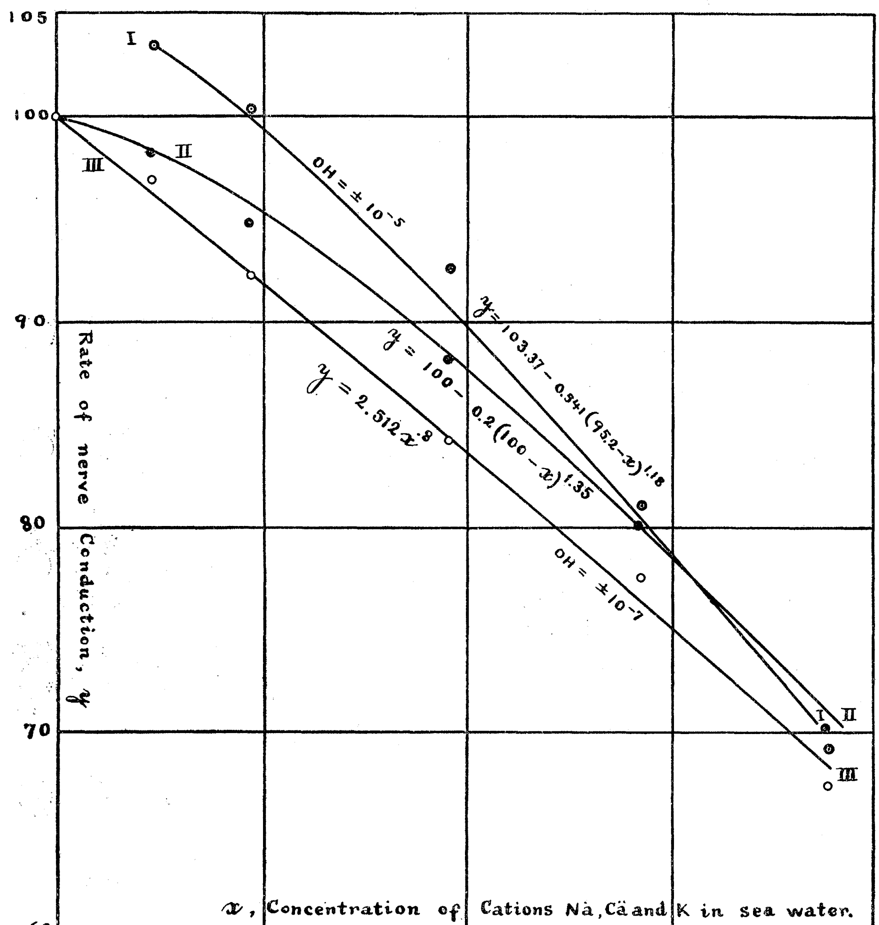

FIG. 2

In Line No. 3 the reaction has passed on to particle B and its negative charge is unmasked, and thus the negative charge passes through the nerve at the rate of nerve conduction until each particle has lost its original cations, and then recaptured others from the surrounding fluid as in Lines 2–7, Line 7 representing the resting nerve after the reaction

has passed through it. Thus by Wilhelmy's law the rate of nerve conduction is proportional to the concentration of the adsorbed sodium, calcium and potassium cations which conduct it.

Since 1899, Loeb[3] has maintained that physiological reactions are phenomena associated with the formation of ion-proteids, but I think that while this is true for nerve conduction it is only half the truth, and that it is possibly a phenomenon of *adsorption* combined with that of an ordinary chemical reaction.

TABLE I

SHOWING THE RATES OF NERVE-CONDUCTION IN CIRCUIT-SHAPED STRIPS OF SUBUMBRELLA TISSUE OF *Cassiopea xamachana* IN SEA-WATER DILUTED WITH DISTILLED WATER. EXPERIMENTS MADE AT TORTUGAS, FLORIDA, JULY 5-16, 1915.

RATES OF NERVE-CONDUCTION

	Natural sea-water $x=100$ (Z)	(Q) 95 s. w. +5 d. w. $x=95.2$	90 s. w. +10 d. w. $x=90.5$	80 s. w. 20 d. w. $x=80.8$	70 s. w. +30 d. w. $x=71.4$	60 s. w. +40 d. w. $x=62.2$
I. Observations of Medusæ Nos. 1–25 in sea-water diluted with alkaline distilled water containing somewhat less than 10^{-6} OH ion concentration, July 5–9, 1915. See curve I I, Fig. 2.......	100	103.37	100.33	92.67	81.09	69.33
Rate (y) calculated from the formula: $y=103.37-0.541\,(95.2-x)^{1.13}$.		103.37	100.00	90.78	80.59	69.87
II. Observed rates of Medusæ Nos. 51–70, July 11–16 in sea-water diluted with distilled water which was less alkaline than in I....................	100	(+) 98.28 ±.96	94.86 ±1.18	88.19 ±1.83	80.12 ±1.61	70.3 ±1.96
Rate (y) calculated from the formula: $y=100-0.2\,(100-x)^{1.53}$............ See Curve II II, Fig. 2.................	100	98.24	95.52	88.59	80.27	70.92
III. Observed rates of Medusæ Nos. 58–71, July 14–16, 1915 in sea-water diluted with nearly neutral distilled water..............................	100	96.86 ±.66	92.25 ±1.62	84.2 ±2.15	77.6 ±1.82	67.5 ±2.14
Rate (y) calculated from the formula: $y=2.512x^{0.8}$...................... See curve III III, Fig. 2................	100	96.15	92.32	84.27	76.38	68.40
The ratio $\frac{x^{0.8}}{\textit{observed } y}$	0.398	0.395	0.397	0.398	0.397	0.403
Rate (y) calculated from the formula: $y=100-0.778\,(100-x)^{1.019}$.....	100	96.15	92.29	84 21	76.29	68.48

Q. 95 cc. sea-water + 5 cc. distilled water.

Z. x = 100 means that the concentration of the cations Na, Ca, and K in natural sea-water is taken to be 100. Then the concentration of the cations in 95 per cent sea-water is 95.2, etc.

+ Probable errors are stated as ± following a determination.

Loeb indeed is not antagonistic to the view that complex changes other than those of a simple chemical reaction may accompany nerve conduction, for he says, *Comparative Physiology of the Brain and Comparative Psychology*, p. 14 (1900): "We have to remember that all life phenomena are due to motions or changes occurring in colloidal substances."

Moreover Matthews,[4] 1902, states that protoplasm consists essentially of a colloidal solution, and stimulation is accompanied by the passing of this solution to or toward a gel; and with these statements I am in accord. Matthews, however, believed the anions to be the stimulating ions, and he also thought the colloidal particles carried a positive charge. Later studies by many observers have made it apparent that the cations are the active agents in most physiological processes, and that living protoplasm is normally alkaline and thus its colloids probably carry negative charges. Moreover the phenomena of adsorption were not well understood in 1902 and Matthews makes no mention of it in respect to nerve conduction.

No one indeed had reason to support the view that adsorption plays a part in nerve conduction until the determination of the change in rate of nerve conduction of *Cassiopea* in successive dilutions of sea-water suggested this as a possibility.

My results lend no support to the theory of Sutherland[5] that the velocity of propagation of nerve impulse is that of a shear in the substance of the nerve. If this were the case its rate would vary with the viscosity of the surrounding fluid, but the decline in rate is practically the same whether the sea-water be diluted with distilled water, 0.9 molecular dextrose, or 0.4 molecular magnesium chloride.

[1] Hardy, W. B., *J. Physiol., Cambridge*, **24**, 296 (1899).

[2] Bayliss, W. M., *Biochem. J.*, **1**, 177 (1906), finds that electrolytes when adsorbed are non-ionized and no longer take part in the electrical conductivity of the solution. See also: *Principles of General Physiology*, p. 54–71 (1915).

[3] Loeb, J., 1899, *Festschrift für Fick*, and *Amer. J. Physiol.*, **3**, 327–338 (1900).

[4] Matthews, A. P., *Science*, **15**, 496 (1902).

[5] Sutherland, W., *Amer. J. Physiol.*, **14**, 112 (1905), and *Ibid.*, **23**, 115 (1908).

ZUÑI CULTURE SEQUENCES

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The vicinity of the famous Indian pueblo of Zuñi in New Mexico has long been known to be rich in ruins. Many of these have been reported and described, some surveyed, and material from various sites has found its way into collections. A large body of specimens was secured through excavations by the Hemenway expedition, but this material and its data remain unpublished.

The region furnishes an unusual opportunity for an attack on the chronology, or at least the sequences of culture, in the prehistory of the